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# AN ELECTRICALLY ADJUSTED COMPENSATED IONIZATION CHAMBER


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WESTINGHOUSE ELECTRIC CORPORATION
ATOMIC POWER DIVISION
PITTSBURGH P. O. BOX 1468 PENNSYLVANIA

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## ABSTRACT

The use of neutron sensitive ionization chambers for neutron flux measurement in nuclear reactors is discussed along with the limitation in neutron detection range because of the gamma ray background in which the chamber must operate. Means of extending this range are also discussed and a new type of compensated ionization chamber is described. The compensation adjustment of this new chamber is made electrically rather than mechanically as in prior compensated chambers. The extension in neutron detection range over that of an uncompensated chamber is of the order of two decades. Frequent adjustment of the compensation is not necessary since the drift is small over a long period of time.

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## INTRODUCTION

Neutron sensitive ionization chambers are normally used for neutron flux measurement in nuclear reactors. Since neutrons do not produce ionization directly, neutron sensitivity is obtained by introducing some material with which neutrons interact to produce ionizing particles. For example, the electrodes may be coated with boron. The isotope $B^{10}$ has a high thermal neutron cross section for the $B^{10}(n, \alpha)Li^{7}$ reaction. One of the product particles is ejected into the gas volume and produces ionization of very high density along its path.

The range of intensity over which the neutron flux may be detected is limited by the gamma ray background in which the chamber must operate. The ratio of the neutron flux to gamma flux at the operating position of a chamber of this type in a reactor core or shield is usually such that the signal due to the neutron flux is about 1000 times that due to gamma rays. Therefore, when the reactor is at full power, the gamma ray background is no problem. However, the gamma rays do not vary directly with pile power as do the neutrons since a large portion of the gamma rays come from induced activities which depend on the history of the reactor. Therefore, a lower limit is set for neutron detection at the level where the ionization due to the neutron flux is equal to that due to gamma rays. This is usually about four or five

decades below full power. The gamma rays which are most important in this respect are those from induced activities in the chamber materials and surrounding materials and from fission products. The beta activities in the chamber materials are also important since these beta particles can produce ionization in the sensitive volume.

## WIDE RANGE IONIZATION CHAMBERS

The range of neutron detection may be enhanced by the following:

1. By locating the chamber in a position with high full power neutron flux and remote from fission products and materials with high induced activities.
2. By selecting materials for chamber construction which have low induced activities.
3. By reducing the sensitive volume of the chamber as far as possible without reducing the neutron sensitivity. The electrode spacing may be made equal to about one-half the range of the alpha particle in the particular filling gas without reducing the neutron sensitivity appreciably.
4. By applying a boron coating of high efficiency in order to obtain maximum neutron sensitivity.

Still further extension of the neutron detection range can be obtained by gamma ray compensation, i.e., by balancing out the component of the signal due to gamma rays. This is accomplished by using two

chambers of approximately equal volume connected electrically so that their outputs subtract. The walls of one chamber are coated with boron. Hence this chamber is sensitive to both neutrons and gamma rays. The other chamber contains no boron and is therefore sensitive to gamma rays only. Since the intensity of the gamma rays may vary from point to point, it is important that the two volumes be as close together as possible in order to obtain equal gamma ray ionization in each volume. A convenient design consists of three concentric cylindrical electrodes as shown schematically in Figure 1. The electrode separating the two volumes is the signal electrode and the other two are high voltage electrodes. By applying a positive voltage sufficiently high to saturate the outer volume between the outer high voltage electrode and ground, practically all the positive ions produced in this volume will be collected by the signal electrode which is maintained at approximately ground potential. Likewise, when a negative voltage sufficiently high to saturate the inner volume is applied between the inner high voltage electrode and ground, practically all the negative ions or electrons produced in this volume will be collected by the signal electrode. If the two volumes are equal and the gamma ray intensity is the same in both and there is no neutron flux present, the negative ions collected from the inner or compensating volume will just cancel the positive ions collected from the outer volume, and the net charge collected by the signal electrode will be zero. In the presence of a neutron flux, there will be additional

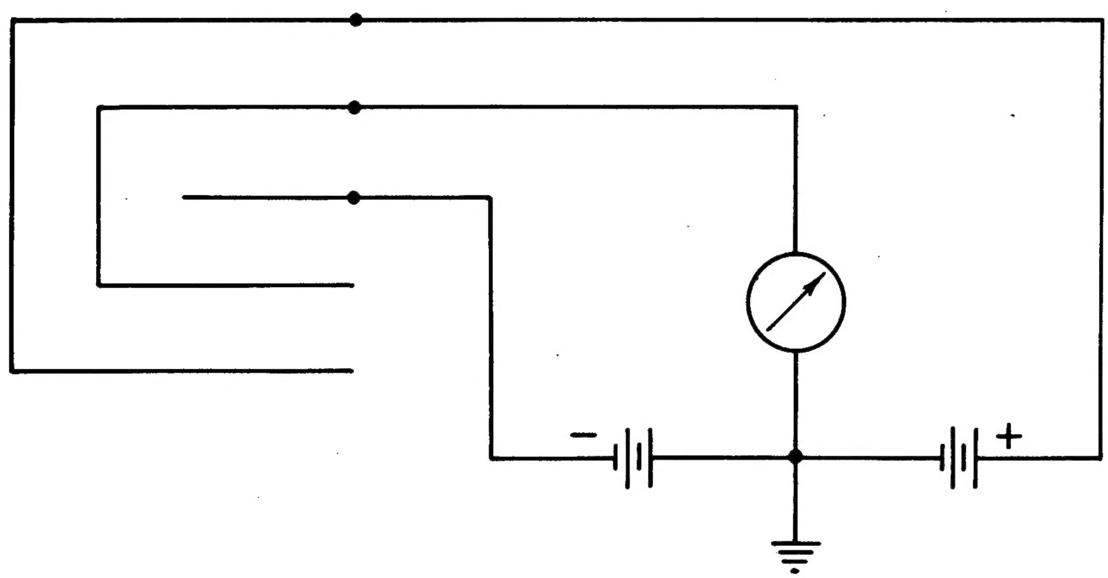

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Fig. 1

ionization in the neutron sensitive volume. In this case, the net charge collected by the signal electrode will not be zero and a current (proportional to the neutron flux level) will flow from the chamber.

Since the gamma flux in and around a reactor varies widely from point to point, the ionization produced in two equal volumes by the gamma rays is seldom the same. For this reason, it is necessary after positioning the chamber to adjust the compensation so that the currents due to gamma rays from the two volumes are equal. The gain in neutron detection range with this type of instrument is normally about two decades. With extreme care in adjustment, a gain of three decades can be obtained. However, small changes with time in the gradient of the gamma flux through the chamber unbalance the compensation somewhat so that a gain of two decades is all that can be expected over a long period of time. In previous designs, the compensation adjustment was accomplished mechanically by varying the size of the compensating volume. Since the adjustment must be made after the chamber is positioned, this type chamber must be readily accessible from outside the reactor.

## ELECTRICALLY ADJUSTED COMPENSATED IONIZATION CHAMBER

A new type of compensated ionization chamber has been developed which is adjusted electrically. Accessibility to the chamber is not required since compensation adjustment can be made remotely. Other advantages of this design are that it is relatively simple and rugged, and sealing is no problem since no mechanical adjustments need be made inside the case.

The electrode configuration is similar to that described previously in that there are three concentric electrodes. In the particular design described, the electrodes are three coaxial cylinders, a partial cross section of which is shown in Figure 2. As will be noted, the inner electrode is grooved. The reason for the grooves will be explained below. As in previous designs, neutron sensitivity is obtained by coating the walls of the outer volume with boron.

A positive voltage sufficient to saturate the outer volume under all operating conditions is applied to the outer electrode, and compensation adjustment is obtained by applying a negative voltage to the inner electrode which is sufficient to saturate only part of the inner volume. The chamber is constructed so that the inner volume is slightly larger than the outer volume; hence, only part of the inner volume need be saturated to obtain a balance in a uniform gamma flux.

Figure 3 shows the shapes of the saturation curves for the inner and outer volumes. Because of the essentially uniform electric field which exists in the outer volume, all portions of this volume become equally saturated at a given applied voltage. Therefore, the entire outer volume is saturated at a relatively low applied voltage. The inner volume does not completely saturate at such a low voltage. Here the current rises sharply at low applied voltages, but slopes off gradually as the voltage is increased and does not saturate until some very high voltage is applied. This is because of the non-uniformity of the electric field which exists in this volume due to the grooves in the inner electrode.

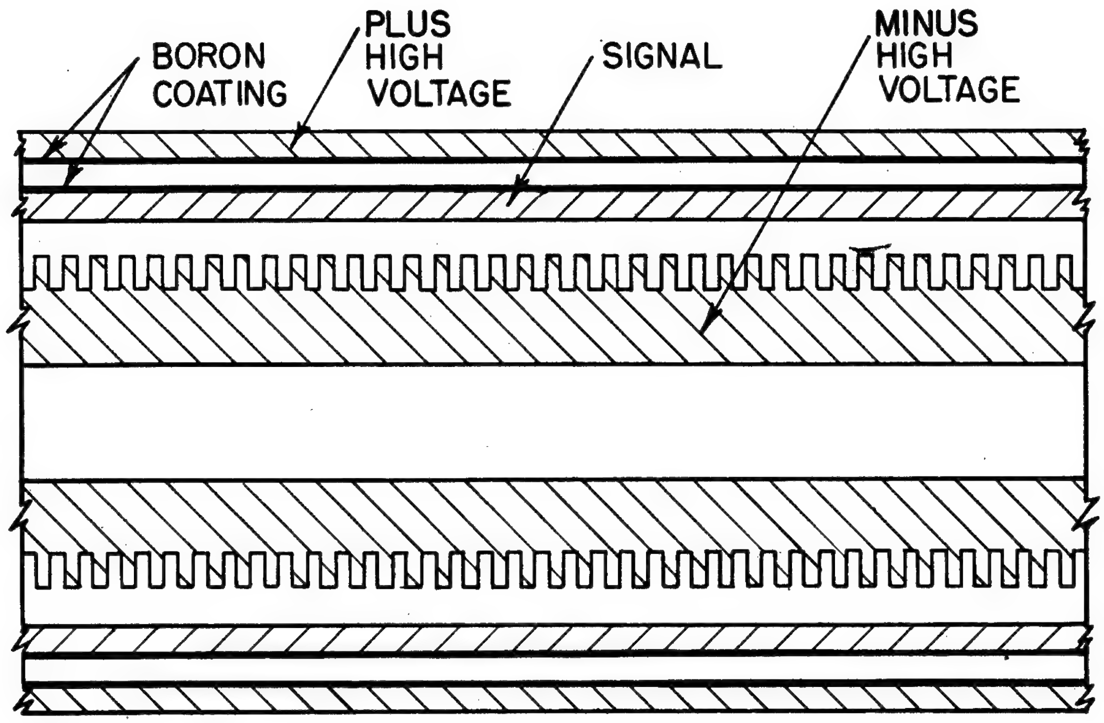


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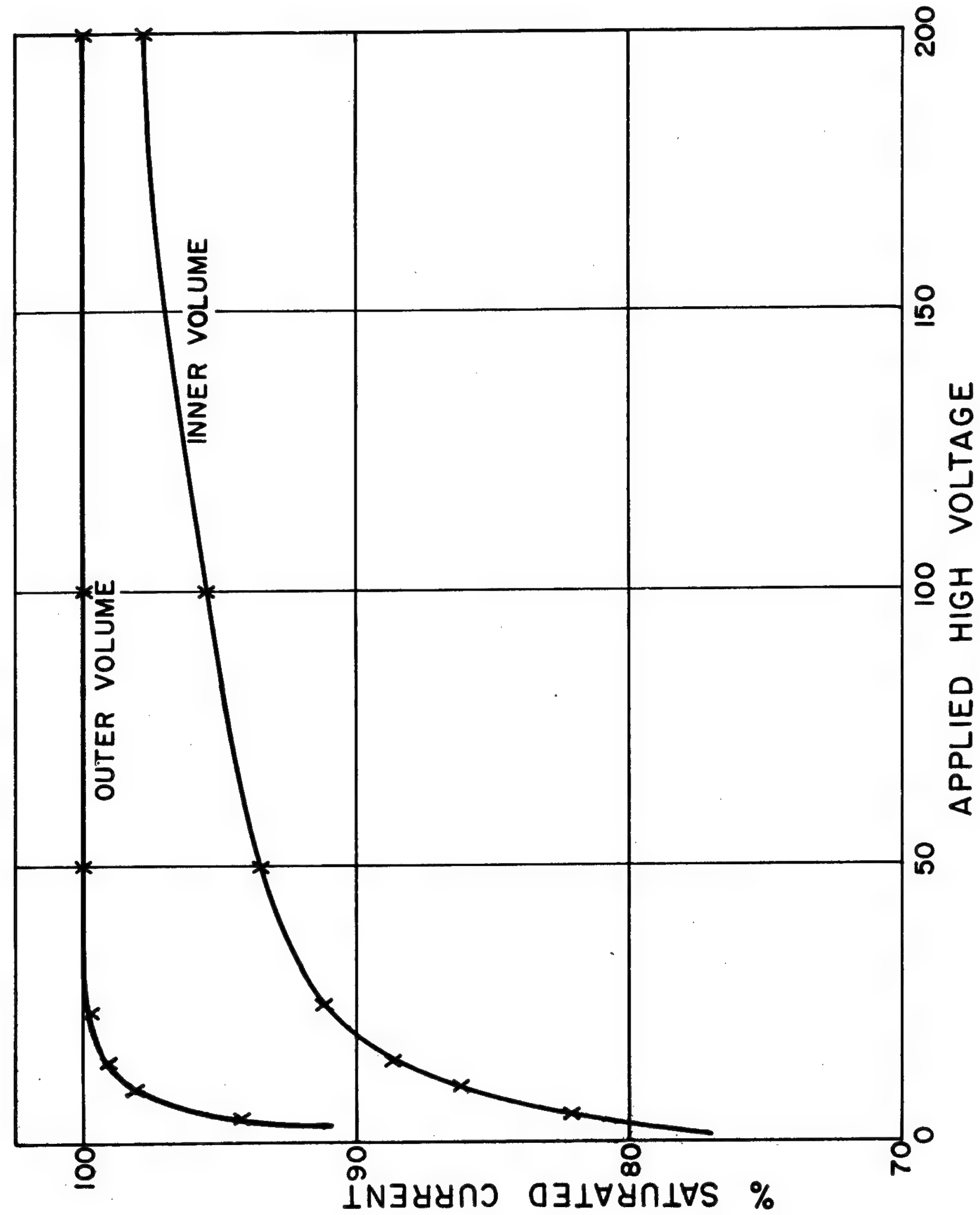
Fig. 2



OUTER VOLUME
INNER VOLUME
APPLIED HIGH VOLTAGE
% SATURATED CURRENT
0
50
100
150
200
100
90
80
70


Fig. 3

Figure 4 shows the resultant output current from the chamber in a uniform gamma flux when the outer volume is saturated by applying a fixed positive high voltage to the outer electrode, and a variable negative voltage is applied to the inner electrode. It will be noted that the shape of this curve is just that of the saturation curve of the inner volume shown in Figure 3. This output, which is the difference between the currents from the two volumes, becomes zero when approximately 95% of the inner volume is saturated, since in this particular design the inner volume is approximately five percent larger than the outer volume.

Since the degree of saturation in a gas is dependent upon the density of ionization, there is a variation with gamma ray intensity in the degree of saturation in those portions of the inner volume which are not completely saturated. However, the discussion below shows that this effect is negligible and that a given compensation adjustment will hold very closely over a wide range of gamma ray intensities. Figure 5 shows the experimentally obtained saturation characteristics of nitrogen at atmospheric pressure in a uniform electric field. Percent saturation is plotted vs. electric field strength. Two curves are shown which correspond to two gamma ray intensities that differ by a factor of over 1000. Figure 6-a shows a plot of equipotential lines in a cross section of the inner volume obtained with an electrolytic tank. Figure 6-b shows a plot of the relative values of electric field strength down the center line of the slot. From the data of Figure 5 and Figure 6-b, the curves of Figure 6-c were obtained

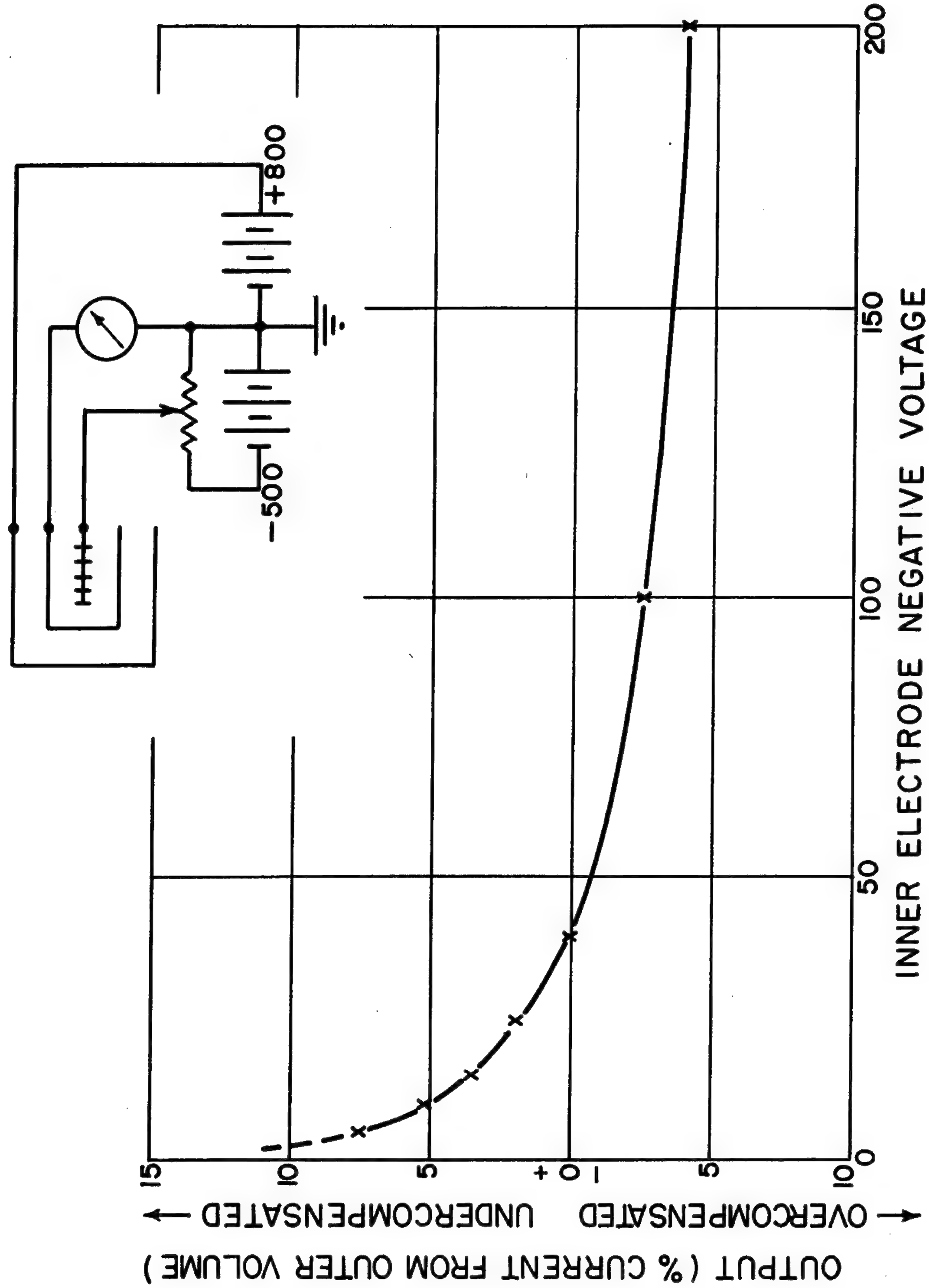

+800
-500
INNER ELECTRODE NEGATIVE VOLTAGE
0
50
100
150
200
15
10
5
+ 0 -
5
10
← UNDERCOMPENSATED
OVERCOMPENSATED →
OUTPUT (% CURRENT FROM OUTER VOLUME)

Fig. 4

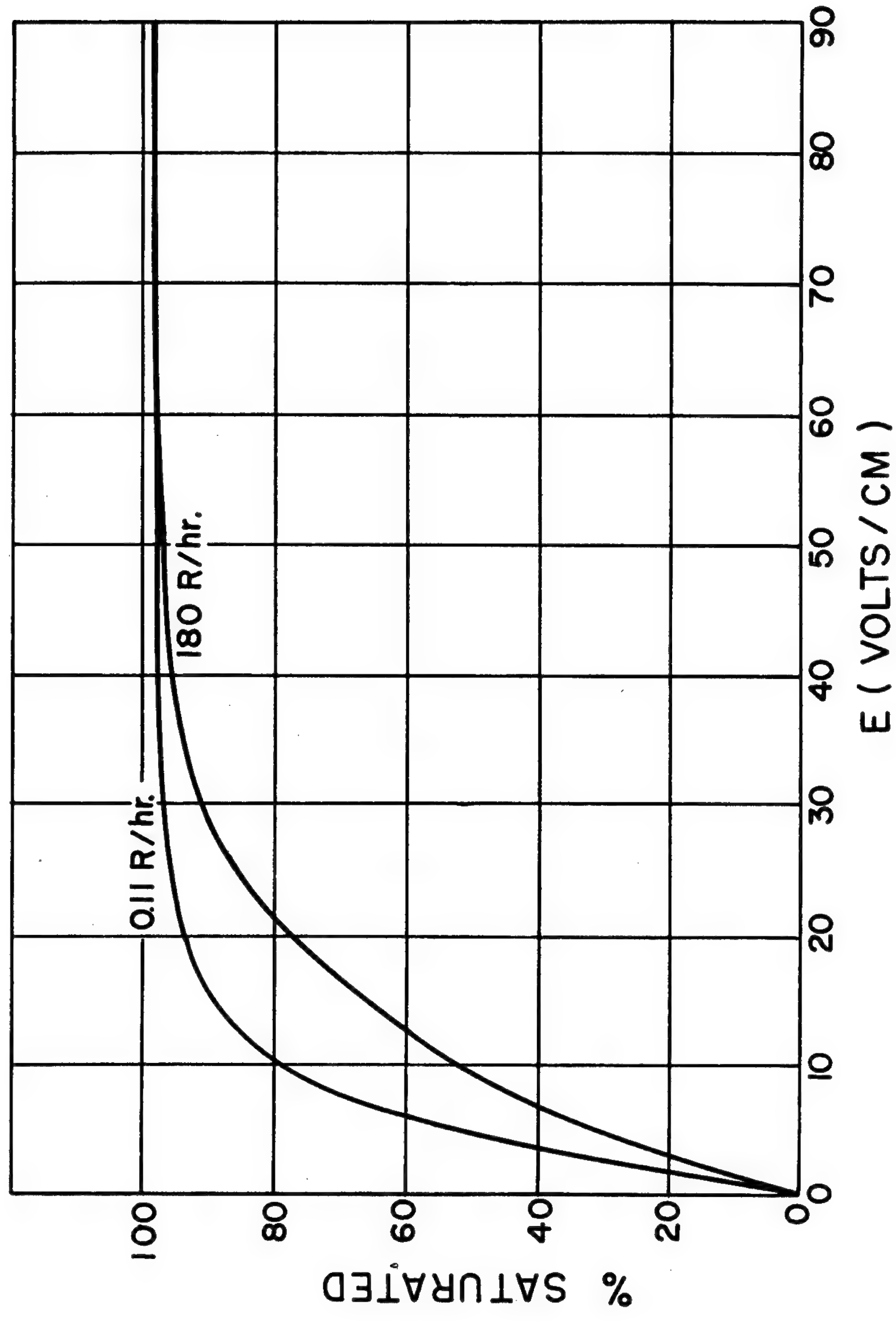

0.11 R/hr.
180 R/hr.
% SATURATED
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
E ( VOLTS / CM )

Fig. 5

388902

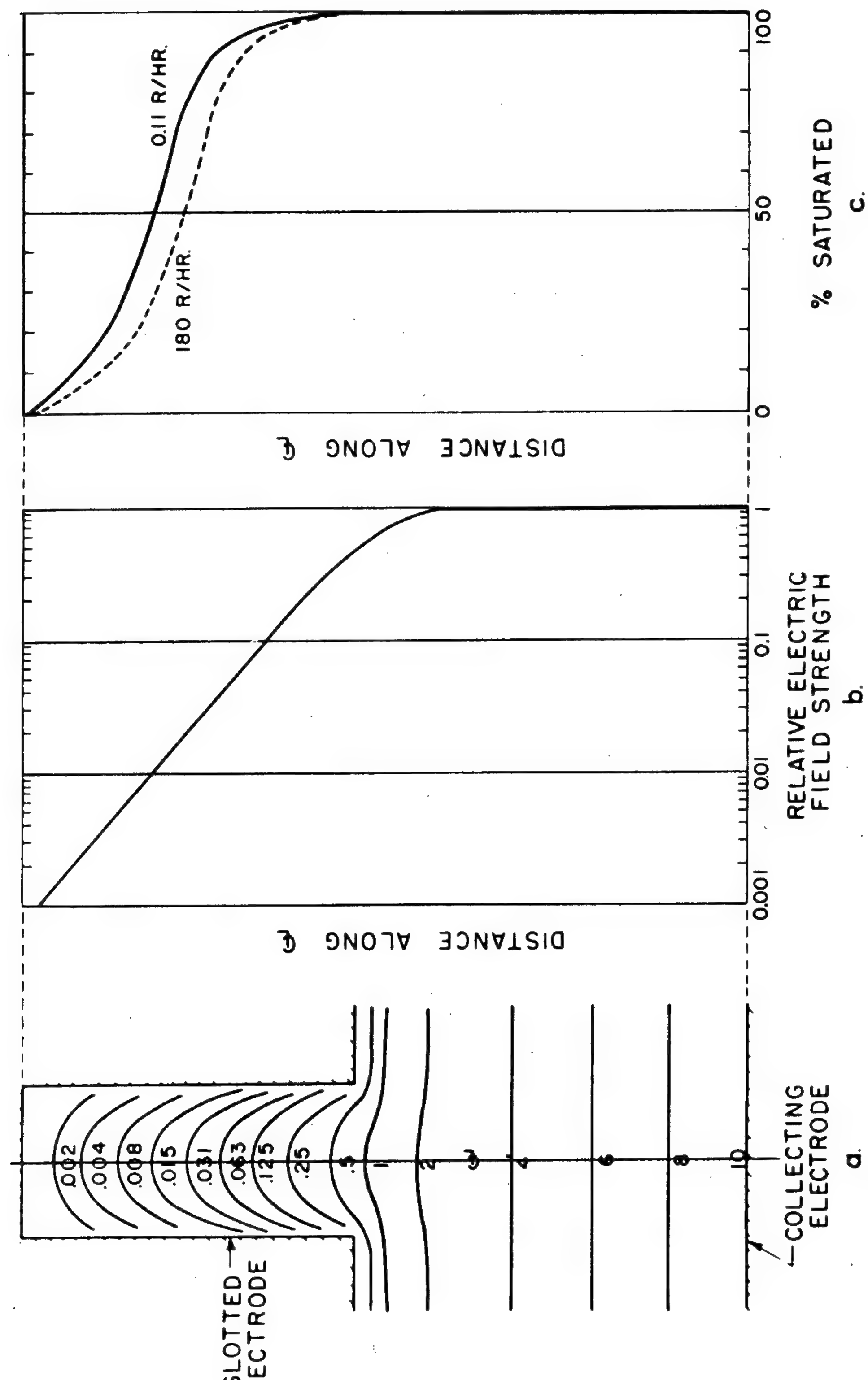

0.11 R/HR.
180 R/HR.
0
50
100
% SATURATED
c.
DISTANCE ALONG ℄
0.001
0.01
0.1
1
RELATIVE ELECTRIC
FIELD STRENGTH
b.
DISTANCE ALONG ℄
.002
.004
.008
.015
.031
.063
.125
.25
.5
1
2
3
4
6
8
10
SLOTTED
ELECTRODE
COLLECTING
ELECTRODE
a.

Fig. 6

which are plots of percent saturation along the center line of the slot with 25 volts applied between the electrodes. As will be noted, the degree of saturation throughout the region between the electrodes is unchanged as the gamma ray intensity is varied from 0.11 R/hr to 180 R/hr except for a slight shift in the bottom of the slot. In the particular design described, this shift is equivalent to a 2% change in the size of the inner volume. This chamber would therefore be expected to remain compensated to within 2% over this range of gamma ray intensities. By making the compensation adjustment shortly after reactor shutdown when the gamma ray background is high, the effect of this shift is made negligible since any unbalance which occurs as the gamma ray intensity decreases is counterbalanced by the decrease in total ionization present. Saturation curves calculated with data from Figures 5 and 6 are shown in Figure 7. The 2% shift in saturation is easily seen here. Figure 8 shows experimental compensation adjustment curves for gamma ray intensities approximately equal to those mentioned above. Here the variation is actually a little less.

## CONSTRUCTION AND OPERATION

A cut away view of the electrically adjusted compensated ionization chamber is shown in Figure 9. The three concentric electrodes are shown enclosed in an outside case which acts as an electrostatic shield and gas tight housing. Connections to the electrodes are brought back through three rigid coaxial cables to the Kovar glass feedthrough insulators. The three connectors on the outside of the case are made to match type HN cable connectors.

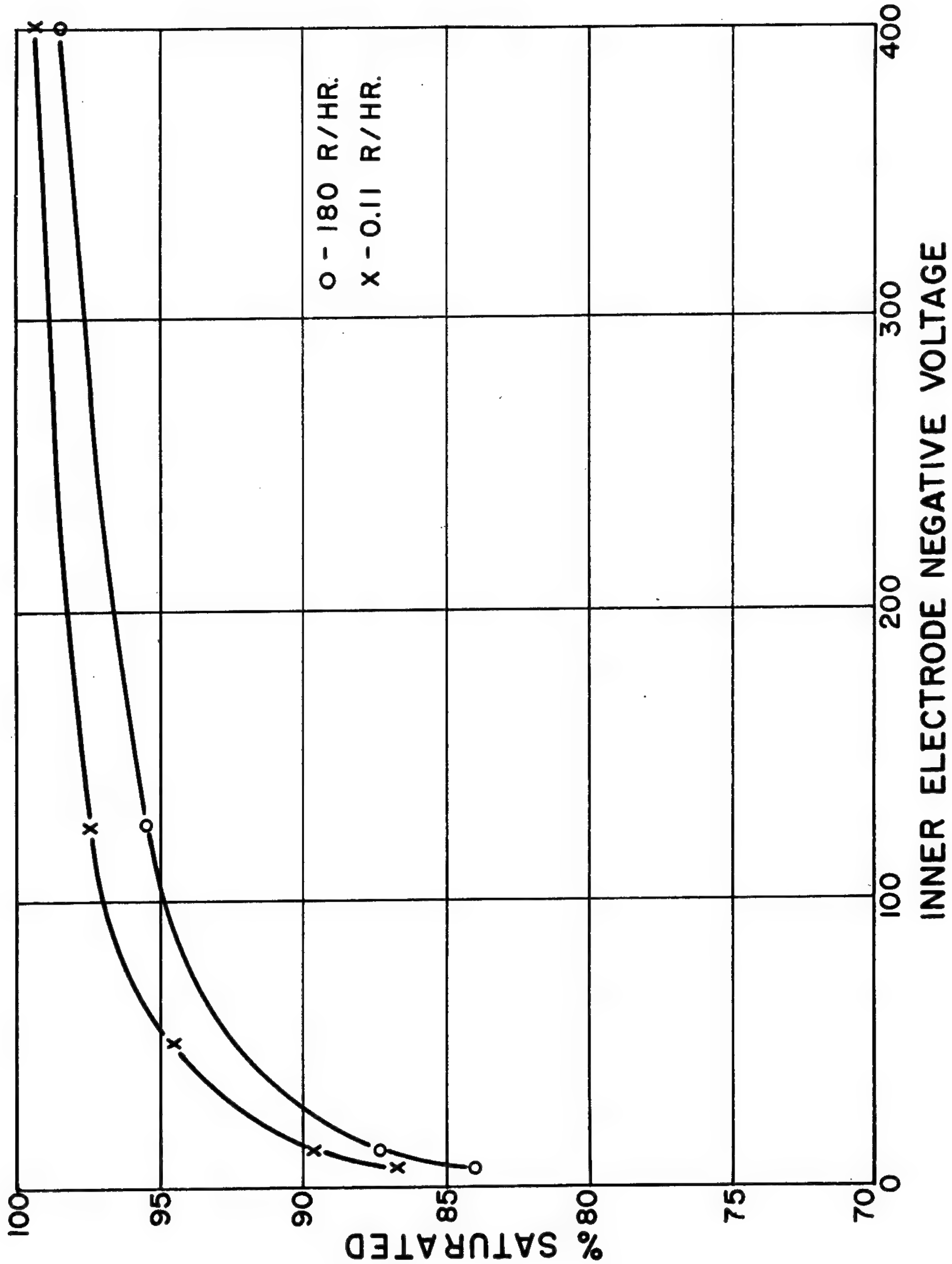

O - 180 R/HR.
X - 0.11 R/HR.
INNER ELECTRODE NEGATIVE VOLTAGE
0
100
200
300
400
% SATURATED
100
95
90
85
80
75
70

Fig. 7

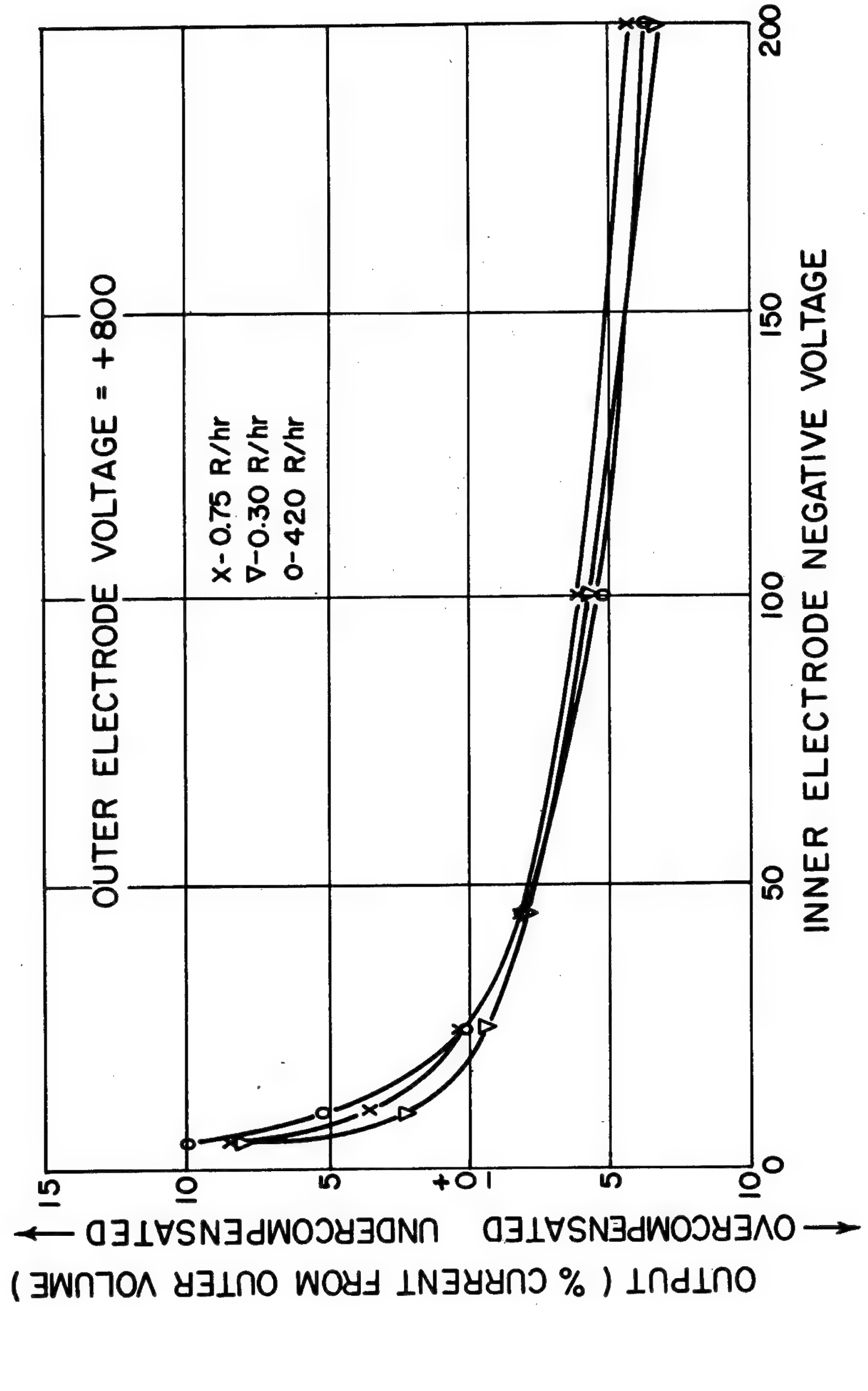

OUTER ELECTRODE VOLTAGE = +800
X-0.75 R/hr
∇-0.30 R/hr
O-420 R/hr
INNER ELECTRODE NEGATIVE VOLTAGE
0
50
100
150
200
OUTPUT ( % CURRENT FROM OUTER VOLUME )
UNDERCOMPENSATED
OVERCOMPENSATED
15
10
5
+0
5
10

Fig. 8

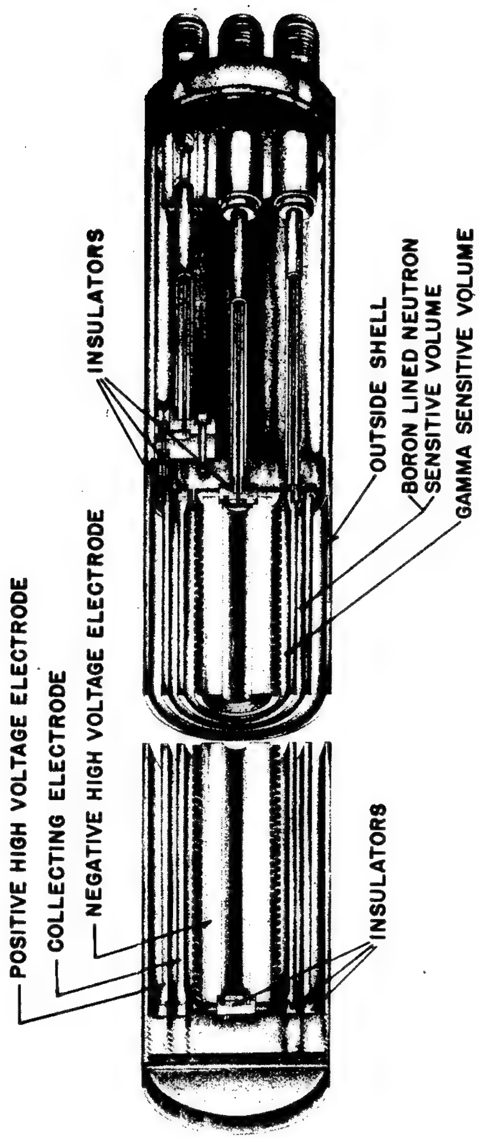



Fig. 9

COMPENSATED ION CHAMBER

With the exception of the Kovar seals and the brass connectors, all metallic parts are made of Dow Chemical Company magnesium alloy 58135 which has a very low induced activity. The Kovar is partially shielded from the neutron flux by a cadmium sleeve which fits around the Kovar inside the chamber. To reduce the effect of induced activity in the seals and connectors, they are located at some distance from the sensitive volumes of the chamber. All insulators with the exception of the glass feed-throughs are polystyrene.

A special technique is used to solder the Kovar seals to the magnesium end cap. The magnesium is tinned with a 60% cadmium, 40% zinc solder which is then allowed to solidify. The Kovar seals are tinned with pure tin. They are then mounted into position in the cap and held under slight spring tension. The entire assembly is brought up to a temperature sufficient to flow the tin onto the Cd-Zn base. Care must be taken not to remelt the Cd-Zn. After soldering in the Kovar seals, the end cap is fitted into position and Heliarc welded. The chamber is then evacuated and filled through the hollow center conductor of one of the Kovar seals. The filling gas is dry tank nitrogen at one atmosphere pressure.

The walls of the outer volume are coated with boron highly enriched in the $B^{10}$ isotope.[1/] Maximum neutron sensitivity is achieved by optimizing this coating thickness. The optimum coating thickness is

1/ The $B^{10}$ is obtained from the AEC Stable Isotopes Division, Oak Ridge, Tennessee.

about 0.5 $mg/cm^2$. However, a coating varying between 0.2 $mg/cm^2$ and 1.0 $mg/cm^2$ gives a neutron sensitivity within 20% of the maximum.2/ The boron is supplied as a colloidal suspension in mineral oil. A uniform coating of proper thickness of this suspension is painted onto the electrodes. To remove the oil, the painted electrode is heated to a temperature of 750°F in an oven evacuated by a fore pump. A large percentage of the oil comes off within about 30 minutes. To remove the remainder, the electrode is held under vacuum and at temperature for a period of about 18 hours. The assembly is then allowed to cool before breaking the vacuum. Though the surface appears perfectly dry, there is a smooth residue of heavy oil which remains on the electrode. This is the binder which holds the boron in place. The coating obtained is such that the chamber neutron sensitivity is approximately $4 \times 10^{-14}$ amperes per $neutron \cdot cm^{-2} \cdot sec.^{-1}$

Gamma ray compensation to better than 2% is obtainable over a long period of time as can be seen in Figure 10. Shown is a semi-logarithmic plot of the chamber output vs. time after reactor shutdown. These curves were taken at intervals over a period of six weeks with the chamber mounted in the Oak Ridge Graphite moderated reactor. The curve marked "uncompensated" shows the output of the chamber when it is operated with no voltage applied to the inner electrode. In this reactor, the only neutrons present after a reactor shutdown are those from the

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2/ Unpublished results of J. C. Gundlach, ORNL.

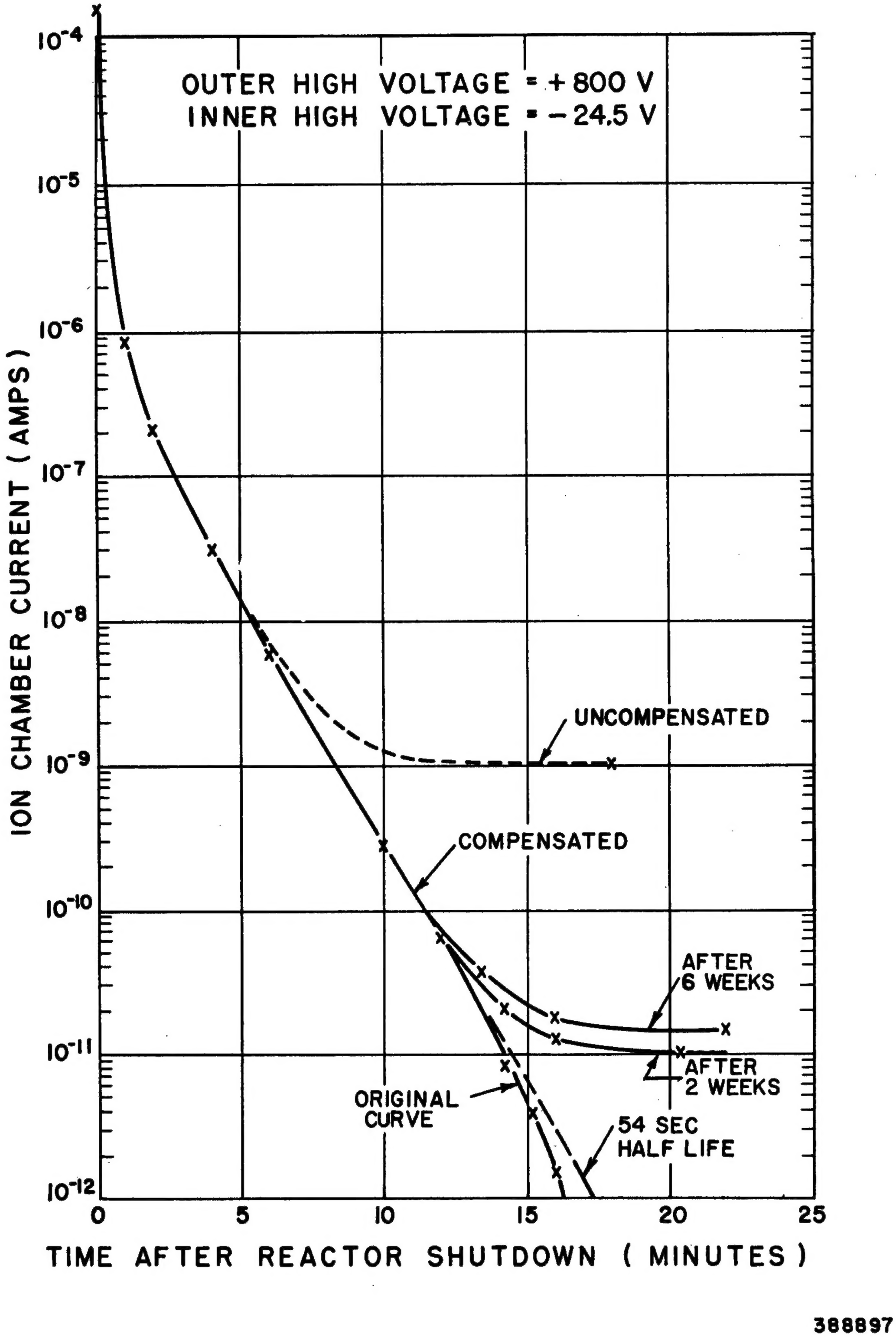
OUTER HIGH VOLTAGE = + 800 V
INNER HIGH VOLTAGE = − 24.5 V
ION CHAMBER CURRENT ( AMPS )
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
UNCOMPENSATED
COMPENSATED
AFTER 6 WEEKS
AFTER 2 WEEKS
ORIGINAL CURVE
54 SEC HALF LIFE
0
5
10
15
20
25
TIME AFTER REACTOR SHUTDOWN ( MINUTES )
388897

Fig. 10

delayed neutron emitters. The short half lived emitters decay rapidly and after several minutes the 54 second half life emitters are the only ones present in any quantity. The dashed line shows the slope of the 54 second half life decay. The other curves show the compensated output at intervals during the six week period. The negative voltage applied to the inner electrode was 24.5 volts. This voltage setting caused the chamber to be overcompensated at first by approximately 0.1% of the uncompensated gamma signal, which accounts for the downward curvature of the original curve. Drift in compensation, probably because of a shift in the gamma gradient, caused the output to be undercompensated by about 1.5% at the end of the period. Since this drift was only 1.6% a gain in neutron detection range of approximately two decades was obtained without readjustment.

## CONCLUSION

The electrically adjusted compensated ion chamber, which is relatively simple and rugged in construction, has been found to operate satisfactorily with an extension of two decades in neutron detection range over that of a comparable uncompensated ion chamber. Compensation adjustment is very easily made. However, experiments indicate that frequent readjustments will not be necessary.

ACKNOWLEDGMENTS

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